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Coronavirus disease 2019—The principles of the curve, explained simply

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Abstract

In the setting of the coronavirus disease 2019 pandemic, the concept of the disease curve has become ubiquitous in medicine and across society. Nevertheless, even among medical specialists, there are common misconception about the curve and how it affects population outcomes. This article provides a simple review of the various population dynamics at play. Principles such as the area under the curve and the threshold of capacity are discussed and simply conceptualized. Understanding the fundamental characteristics of a problem can allow us to see it with more clarity. By the end of the article, the reader will gain an effortless a sense of insight on this topic.

KEYWORDS

area under the curve, capacity, coronavirus, COVID, curve

Much has been discussed about the curve of COVID-19 as it ravages through our countries, our cities, our homes. Politicians readily refer to it in addressing the various nations of the world. They ask us to "flatten the curve to save lives." [1,2] Effectively, the way to flatten the curve is to abide by social distancing measures.

Nevertheless, even among medical specialists, there are common misconception about the curve and how it affects population outcomes. Understanding the fundamental characteristics of a problem can allow us to see the problem with more clarity. Herein, I aim to provide a simple understanding of the various population dynamics at play. We will review how principles such as the *area under the curve* and the *threshold of capacity* can be conceptualized.

The discussion will begin as rudimentary. However, it will add gentle layers of complexity. Hopefully, by the end, it will provide the reader a sense of insight.

1 | DEFINING THE CURVE

1.1 | What are its axes?

The X axis is a measure of time.

The Y axis represents the number of people affected during that time (the rate), may it be by infection, mortality, or recovery depending on the type of curve.

1.2 | "The curve," is there only one?

Although this concept of "The Curve" is often referred to as a single entity, there are actually various curves a play. In a simple way to conceptualize the population dynamics, we can define three fundamental curves: the infection curve, the mortality curve, and the recovery curve.

The *infection curve* describes the rates of COVID-19 infection across our society. (Figure 1).

The *mortality curve* describes the mortality rates across society. The peak of this curve is offset to the right on the X-axis as compared to the infection curve (Figure 2). The peak to peak delta (X_{PM}- X_{PI}) will correspond to the average time duration between infection diagnosis and mortality.

The recovery curve describes the recovery rates across society. The peak of this curve is offset to the right on the X-axis as compared with the infection curve (Figure 3). The peak to peak time difference (ΔX) will correspond to the average time duration between infection diagnosis
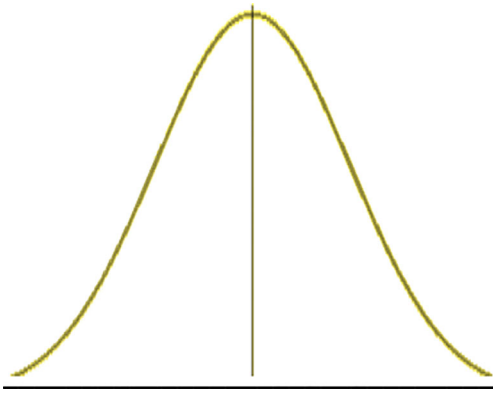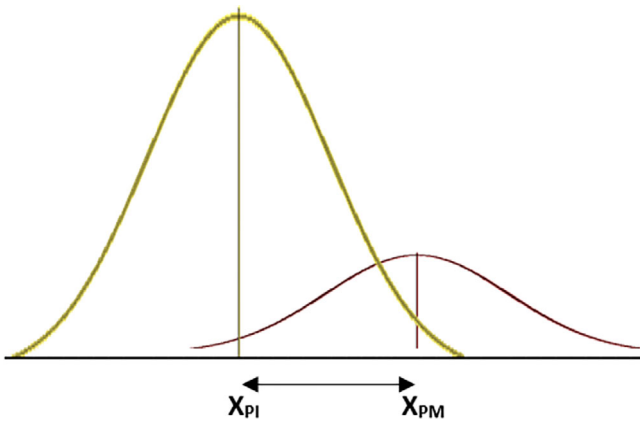
FIGURE 1 Infection curve (yellow)

FIGURE 2 Infection curve and Mortality curve (red). XPI, X axis value at peak of infection curve; XPM, X axis value at peak of mortality curve
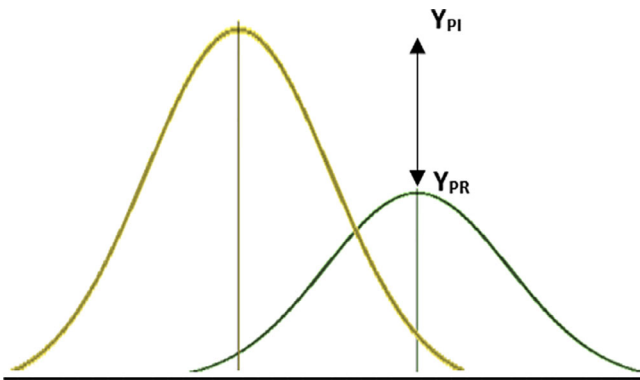

FIGURE 3 Infection curve, Mortality curve, and Recovery curve (green). YPR, Y peak recovery, YPI, Y peak infection

and recovery. The corresponding peak to peak population ratio delta-Y will represent the number of people who passed away at the peak. The peak to peak ratio ($Y_{peak-recovery}/Y_{peak-infection}$) will represent the recovery rate at the peak of disease (Figure 3).

1.3 | Area under the curve, what does it represent?

Without discussing the calculus of these functions, understanding the "area under the curve" is *integral* to conceptualizing these curves. The 2-dimensional shaded area below the curve will represent the total number of cases. We will designate this area as AUC. Depending on the type of curve, it will represent the total number of measured infections, mortalities, and recoveries. Hence, the following formula will apply:

AUC infection = AUC mortality + AUC recovery.

In other words, the total number of people infected will be equal to the number of people who pass away added to the number of people who recover (Figure 4).

2 | HOW EXTERNAL FACTORS SAVE LIVES

2.1 | Flattening the curve does not necessarily save lives on its own

To save lives, you must decrease the area under the Mortality Curve. Flattening the curve will inherently modify the rates of infection, mortality, and recovery. By flattening the curve with social distancing, the shape of the curve is different, the slopes of the tangents are different. However, the area under the curve does not necessarily change. Flattening the curve, can *bring down the peak* and *widen the base*, *maintaining the same AUC* (Figure 5).

Dr Robert Katz, founding director of the Yale-Griffin Prevention Research Center, has been quoted on this topic: "If all we do is flatten the curve, you don't prevent deaths, you just change the dates".[3]

This is why, to save lives, you must decrease the area under the curve. Flattening the curve, does not necessarily achieve that on its own. It has the potential to save lives when combined with the following factors.

2.2 | Avoiding the threshold of hospital capacity. We cannot all get sick at once

Avoiding the threshold of hospital capacity is one way by which "flattening the curve" can save lives.[1,4] By threshold of capacity, I am referring the maximal number of people the health care system can accommodate. Once we reach that limit, mortality rises, not because we could not have saved those lives. It rises because we do not have the resources to save them (Figure 6).

Basically, we cannot all get sick at the same time. That's because there aren't enough ICU beds or ventilators.

FIGURE 4 Comparing the area under the curve. The infection and recovery curves are superimposed. The difference between the areas under the curve of these two will correspond to the area under the mortality curve

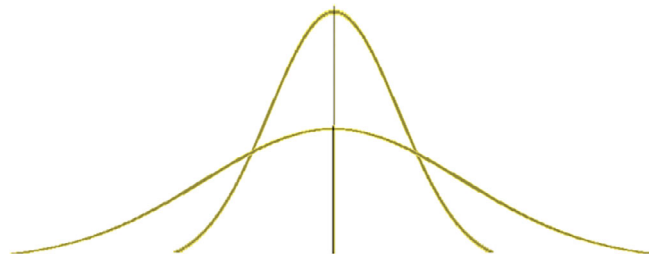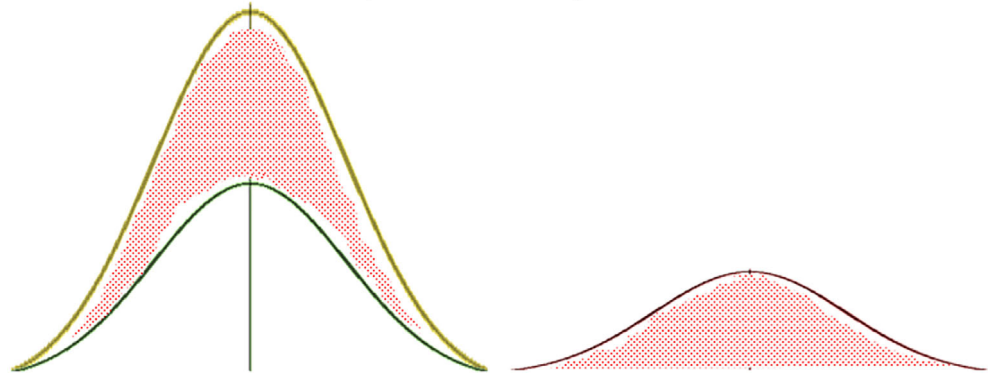AUC infection - AUC recovery = AUC mortality

FIGURE 5 Peak and base alterations by flattening the curve

2.3 | A potential cure. Buying time until a vaccine or remedy

Flattening the curve can also potentially save lives because it buys us time until we find a cure, preventive vaccine, or effective remedy.

If a cure is found, then the AUC at the tail end of the flattened infection curve will be larger than that of a non-flattened curve. Those are effectively less people infected (on the infection curve), and lives saved (on the mortality curve) (Figure 7).

The AUC after the cure represents the number of people who avoided the illness. That number is larger on a flattened curve. Ergo, flattening the curve can save more people from being infected if a cure is found.

3 | HOW DOES THIS TRANSLATE TO A STRATEGY? THREE TIERS

Putting all this together, there are three fundamental interventions governments can enact to decrease the mortality.

3.1 | Strategy 1. Flatten the curve, bring down the peak

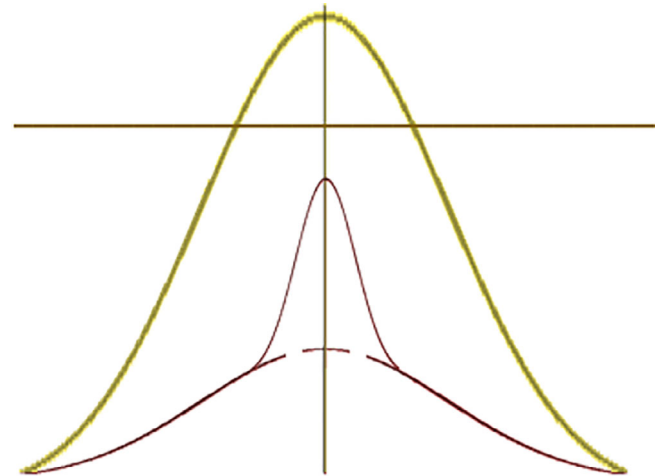Social distancing measures will bring down the peak of the curve (Figure 8).

FIGURE 6 Effects of surpassing the threshold of hospital capacity. The horizontal line represents the threshold of hospital capacity. Once the infection curve surpasses it. There is a corresponding sudden surge in the mortality curves. NB: The mortality and infection curves have been superimposed and depicted symmetrically for ease of discussion

3.2 | Strategy 2. Raise the threshold of hospital capacity

This consists of building more ventilators, increasing the number of ICU beds, ICU personnel, emergency room, and medical ward capacity (Figure 9).

Basically, the aim is to raise the threshold of hospital capacity so high, that the curve does not cross it.

3.3 | Strategy 3. Invest in a cure or treatment

An earlier cure in combination with a flattened curve will maximize the number of lives saved (Figure 10).

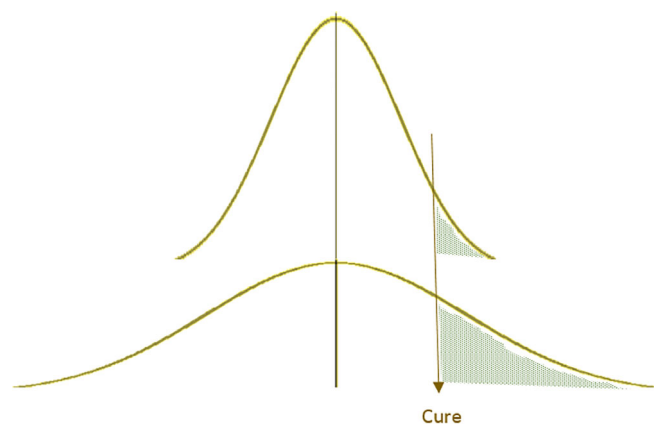To be clear, such strategies are designed strictly to minimizing mortality across society during the pandemic.

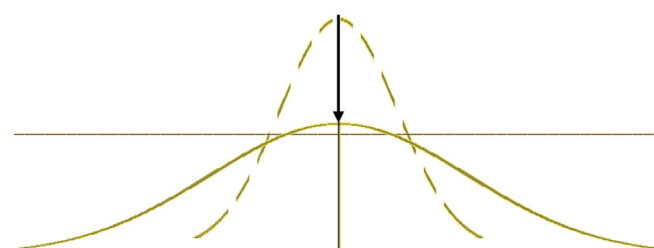**FIGURE 7** Comparing the effect of a cure on a flattened and non-flattened curve
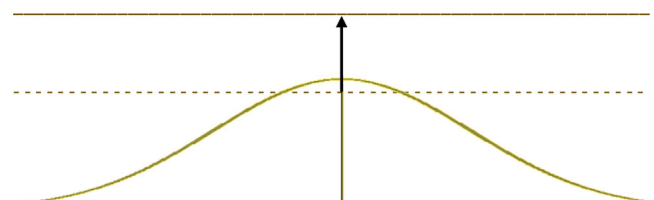

FIGURE 8 Strategy 1: Bring down the peak

FIGURE 9 Strategy 2: Raise the threshold

This article does not discuss strategies on returning to normalcy. Nevertheless, the ideal trigger to transition from one strategy to the other would be the development of a cure such as a vaccine or effective treatment.

FIGURE 10 Strategy 3: Earlier cure

However, if this cannot be found in time, our only option may be to gradually return to life on the down-slope of the curve. Doing so, hoping that herd immunity may provide protection to the vulnerable. In such a scenario, mathematical modeling could to inform us on which part of the curve would optimize herd immunity and minimize a rebound.

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